Energy Management Operations for the InSight Solar-powered Mission at Mars

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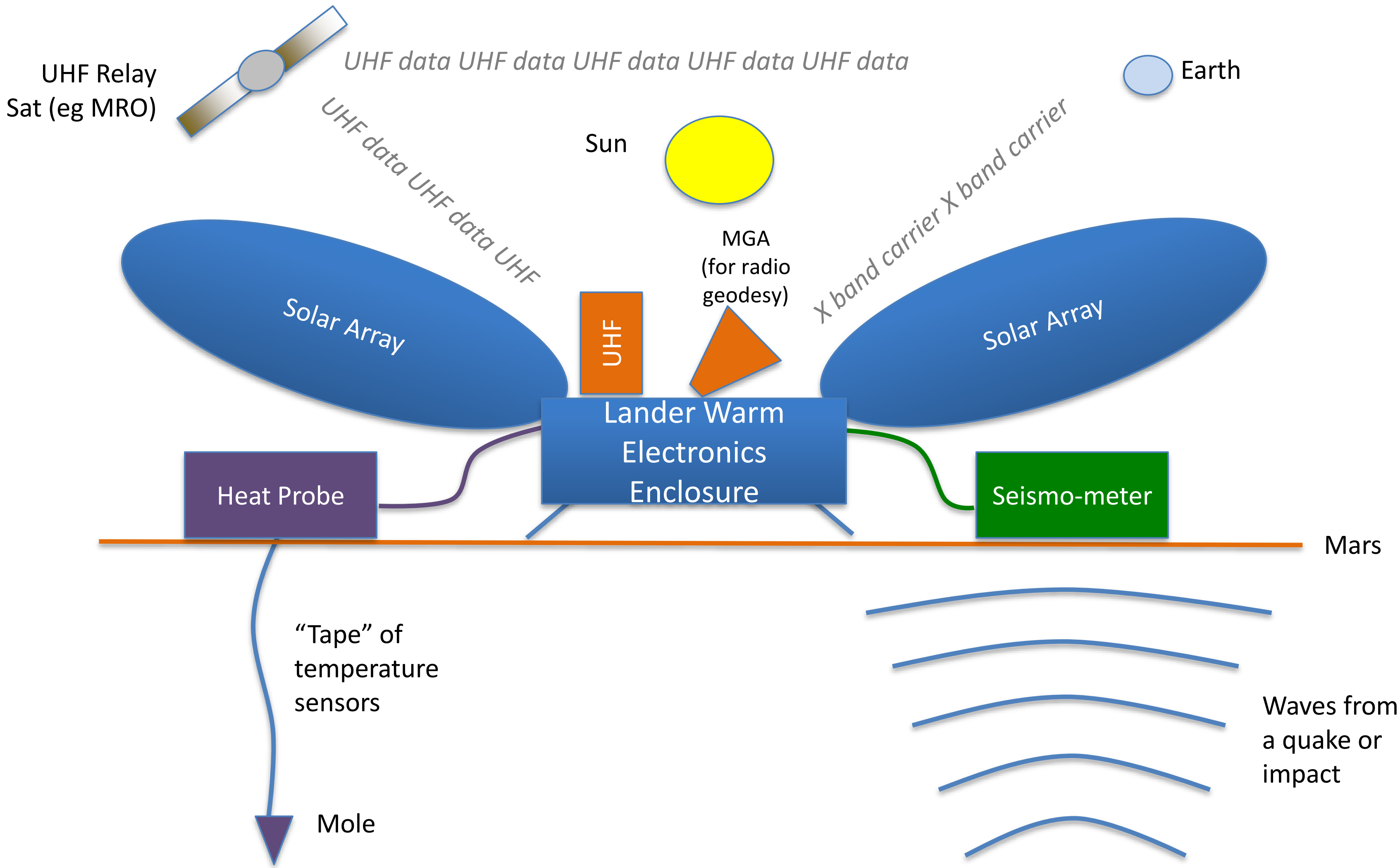
Introduction / Overview

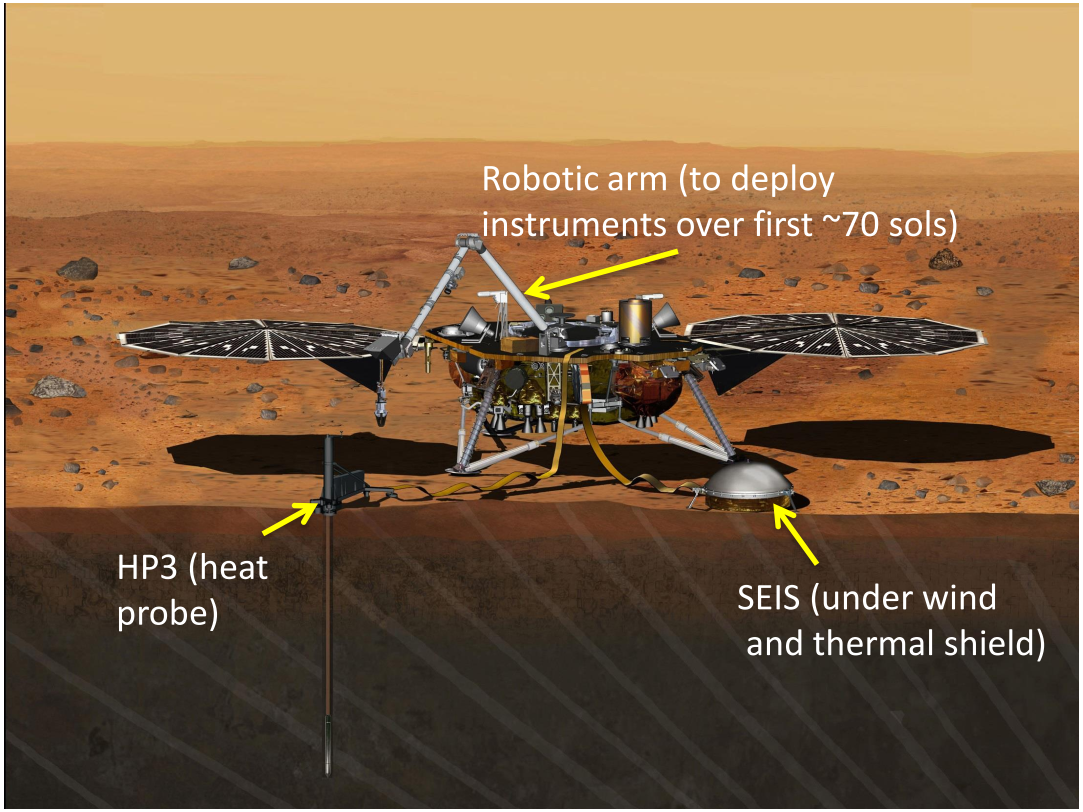
- (Re-)introducing the InSight Mission
- Atmospheric dust, what we know and how we know it
  - And how it influences InSight Energy Management policies in operations

InSight Mission Overview

- **InSight** is a NASA Discovery mission to Mars, currently in development, with planned launch in May 2018 and arrival at Mars in November 2018.
- The central science goal of InSight is to place a high-precision seismometer on the surface of Mars, and then collect seismic data with it for ~1 Mars year
  - To measure Martian crust, mantle and core properties
- In addition, over the Mars year InSight will:
  - make X-band doppler radio measurements of the nutation rate of the planet,
  - measure local atmospheric pressure, magnetic fields, wind speed and temperature,
  - and also lower a heat flux measurement probe several meters into the crust.

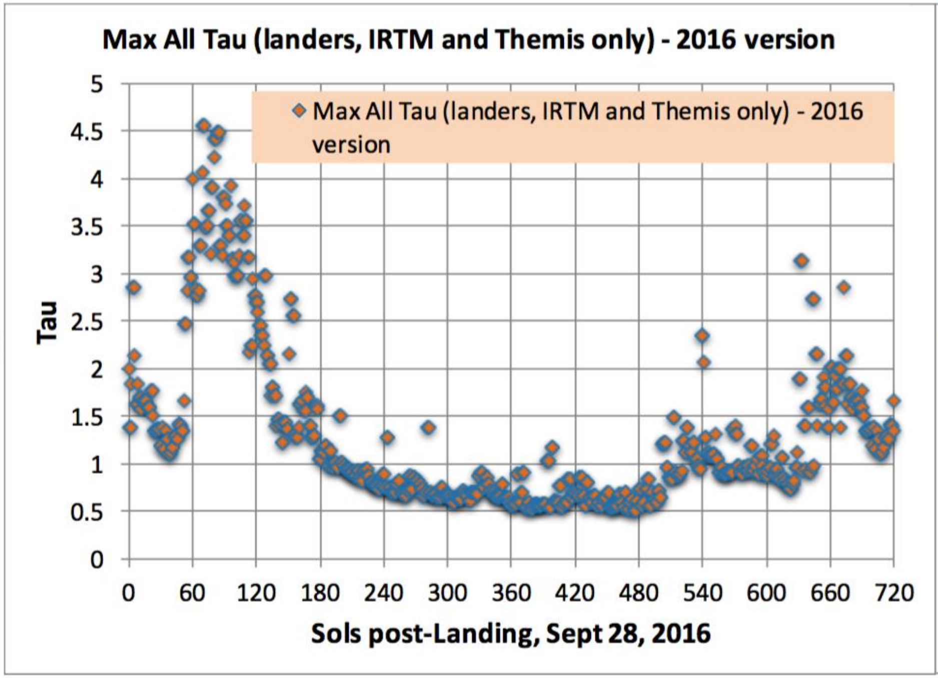

UHF Relay Sat (eg MRO)
UHF data UHF data UHF data UHF data UHF data
UHF data UHF data UHF
Earth
Sun
X band carrier X band carrier
MGA (for radio geodesy)
UHF
Solar Array
Solar Array
Lander Warm Electronics Enclosure
Heat Probe
Seismo-meter
Mars
“Tape” of temperature sensors
Mole
Waves from a quake or impact

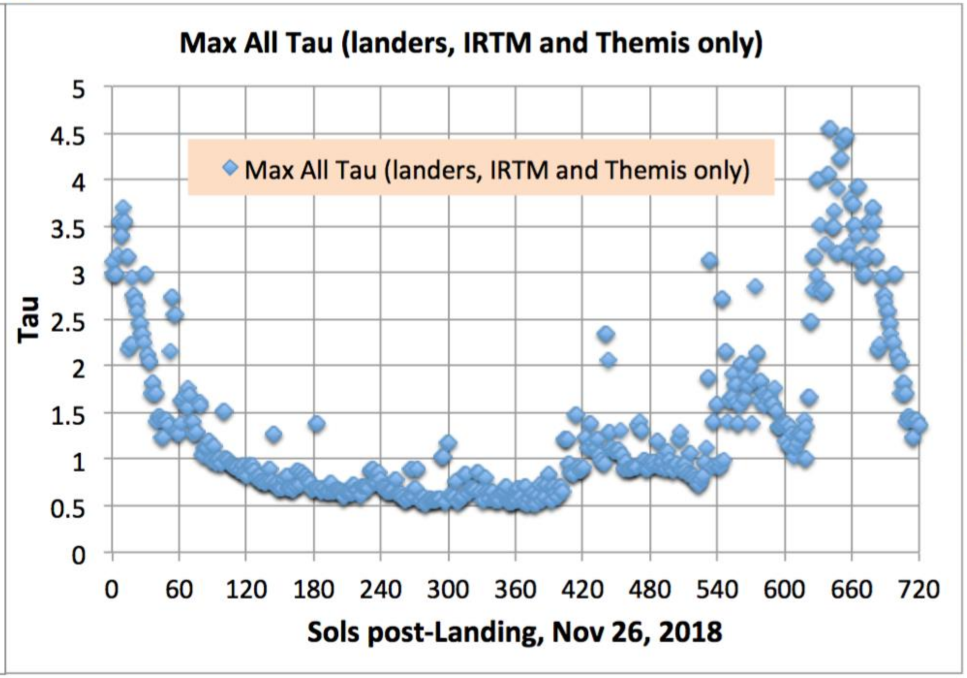
InSight Solar Powered Spacecraft Derived from Phoenix Design



- InSight is the first solar-powered Mars lander designed to operate for an entire martian year.
  - 2 solar arrays (totaling ~5 m^2 collecting area) with triple-junction photovoltaics
  - 2 Li-ion batteries (unlike MER, <u>no</u> radioisotope heaters to warm the batteries)

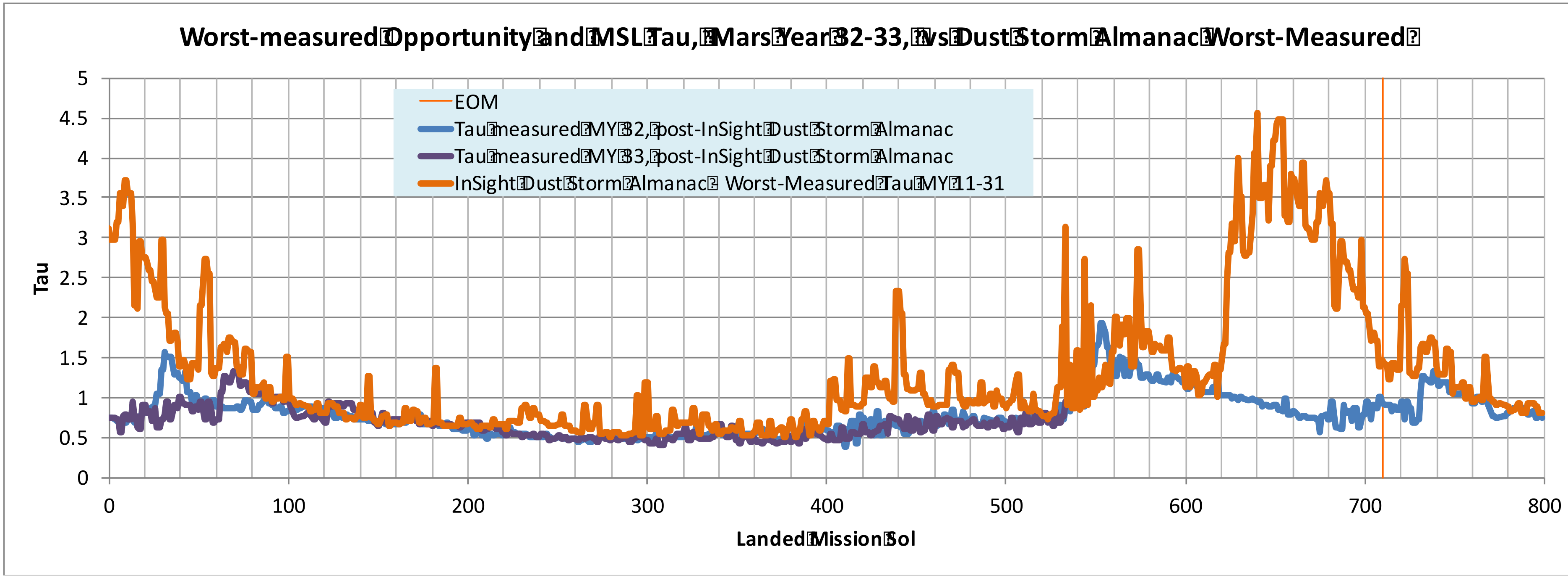
2018 vs 2016 Dust Storm Almanac Worst-observed Tau per Sol





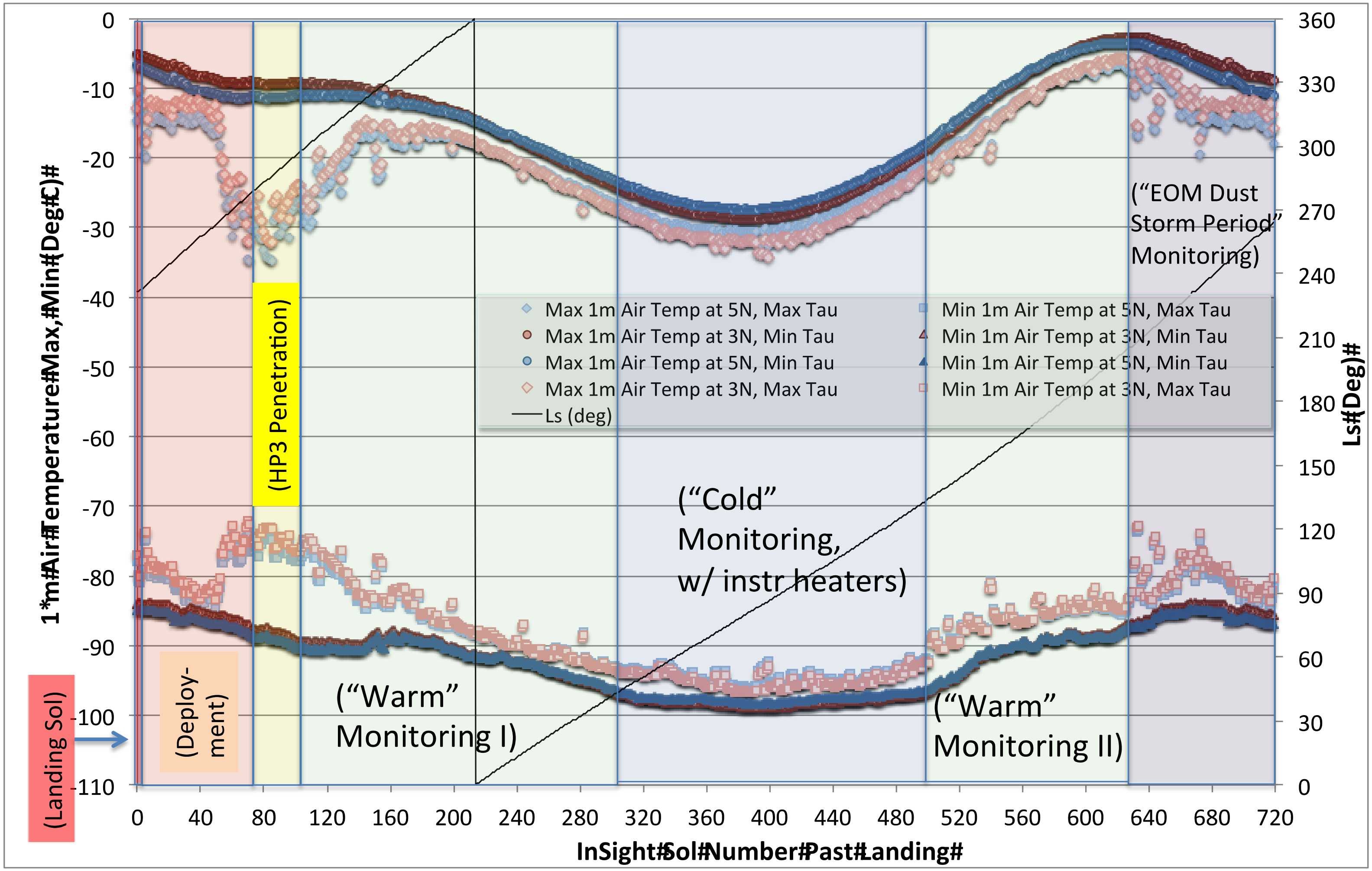
- (Describe differences and their impacts on surface energy)
- Also note no-wind-cleaning exponential dust accumulation policy, and use of analysis with worst-case N or S tilt of the lander solar arrays.

Mars Dust Activity Since Last Almanac Update (in May 2015)



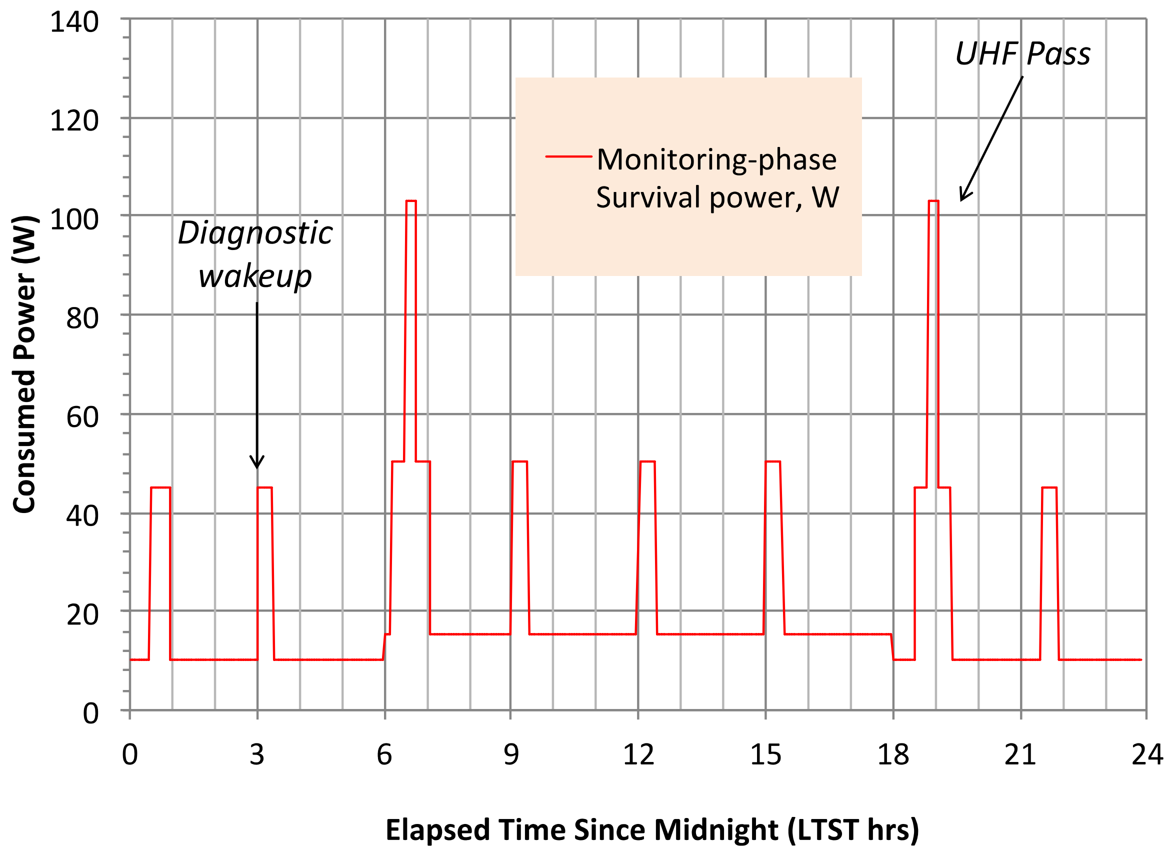
- Point out how only one minor regional dust storm (mapping to around sol 40/550)
- Also note no-wind-cleaning exponential dust accumulation policy, and use of analysis with worst-case N or S tilt of the lander solar arrays.

Energy View of Surface Mission Timeline (Tau & Temperature)



- Above shows sol-by-sol 1-m air temperature range, at minimum and maximum tau conditions
- High-tau periods apparent in temperature variability near start and end of mission
- We must also handle heater loads during *mid-mission aphelion cold season* (around sol 400).
- InSight temperatures are ~12C colder and ~18C hotter than Phoenix required environments.

Typical Daily Power Loads Profile for InSight

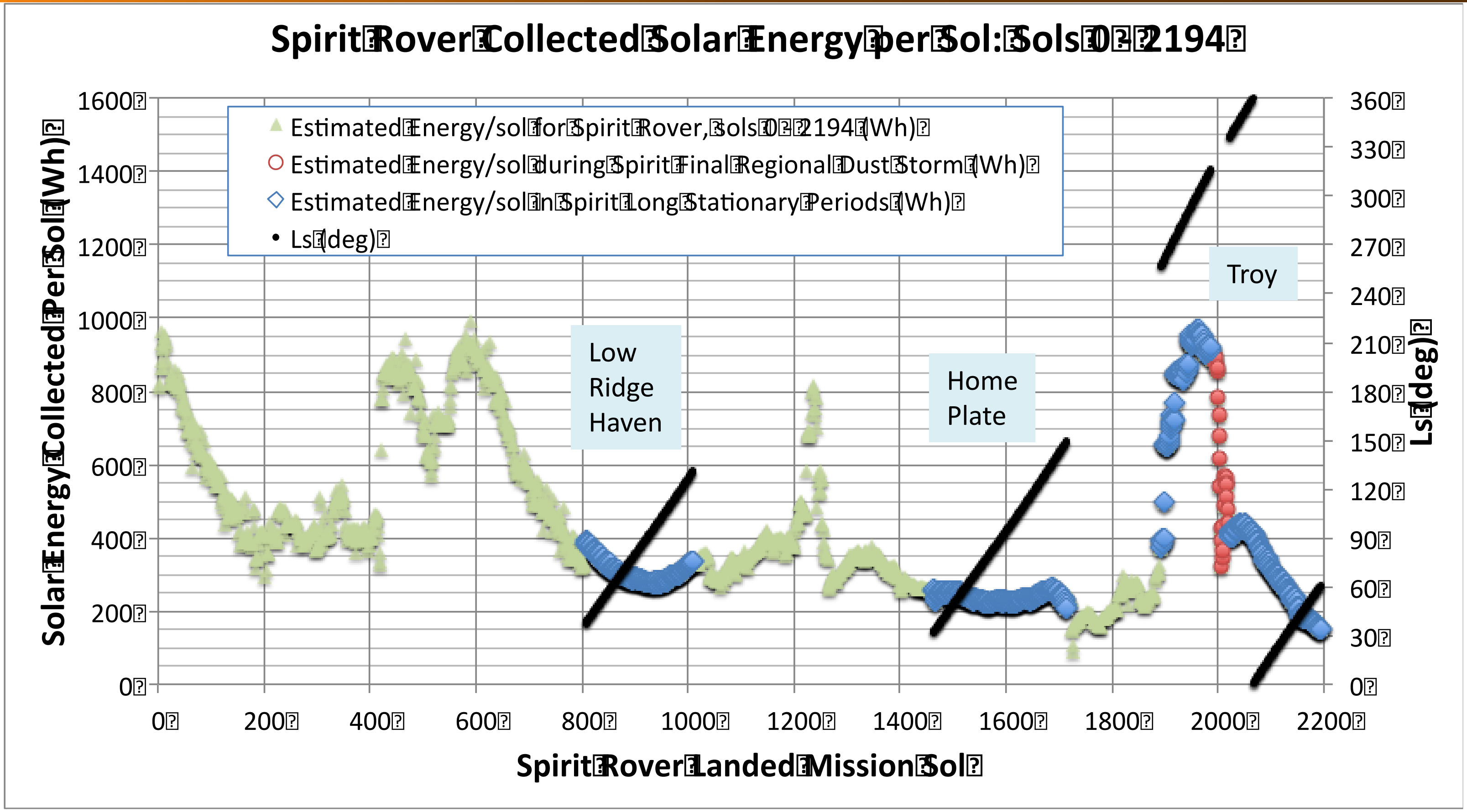


- (Discuss main features)
- (Discuss variants – survival vs science and deployment profiles)

Mapping *Energy Profile* to *Instrument Activation State*

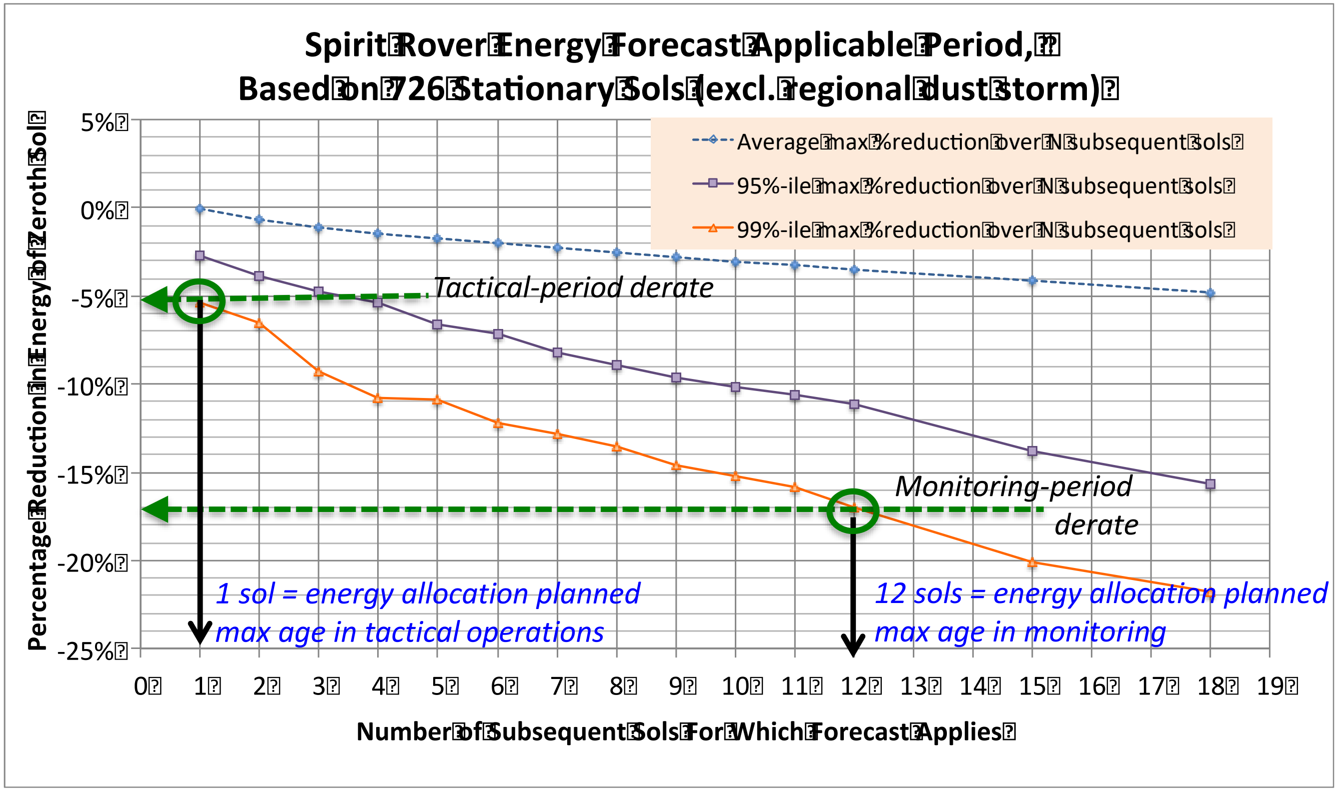
		Conserve			
	Full Monitoring	**“HP^3 On”**	**“Seismology”**	**Minimum Monitoring**	**Survival**
SEIS – Seismometer					
VBB sensors					
SP sensors					
HP^3 – Thermal Probe					
HP^3 temp sensors			*(ON if unallocated margins allow)*		
Radiometer			*(ON if unallocated margins allow)*		
APSS – SEIS Auxiliary Payload Sensor Suite					
Pressure Sensor					
Magnetometer	*(except in cold season when SEIS heater is on)*	*(except in cold season when SEIS heater is on)*	*(except in cold season when SEIS heater is on)*		
TWINS (temp, wind sensors)					
Bus Voltage Monitor					
Thermostatic Heaters					
Operational (Spacecraft)					
Survival (Spacecraft)					
Survival (IDA motors)	[TBD]	[TBD]	[TBD]	[TBD]	In Deployment

How does an energy predict's validity change over time?



- The estimated daily energy of the MER rovers are unique observations of the transient effects on solar energy generation by Mars surface environments.
  - Data shown for Spirit rover extended stationary periods (blue and red symbols) in dusty and clear seasons (for conservativeness, Spirit chosen over Opportunity data).
  - These stationary-rover energy data were used to obtain statistics on the variability of solar energy over periods of several sols.

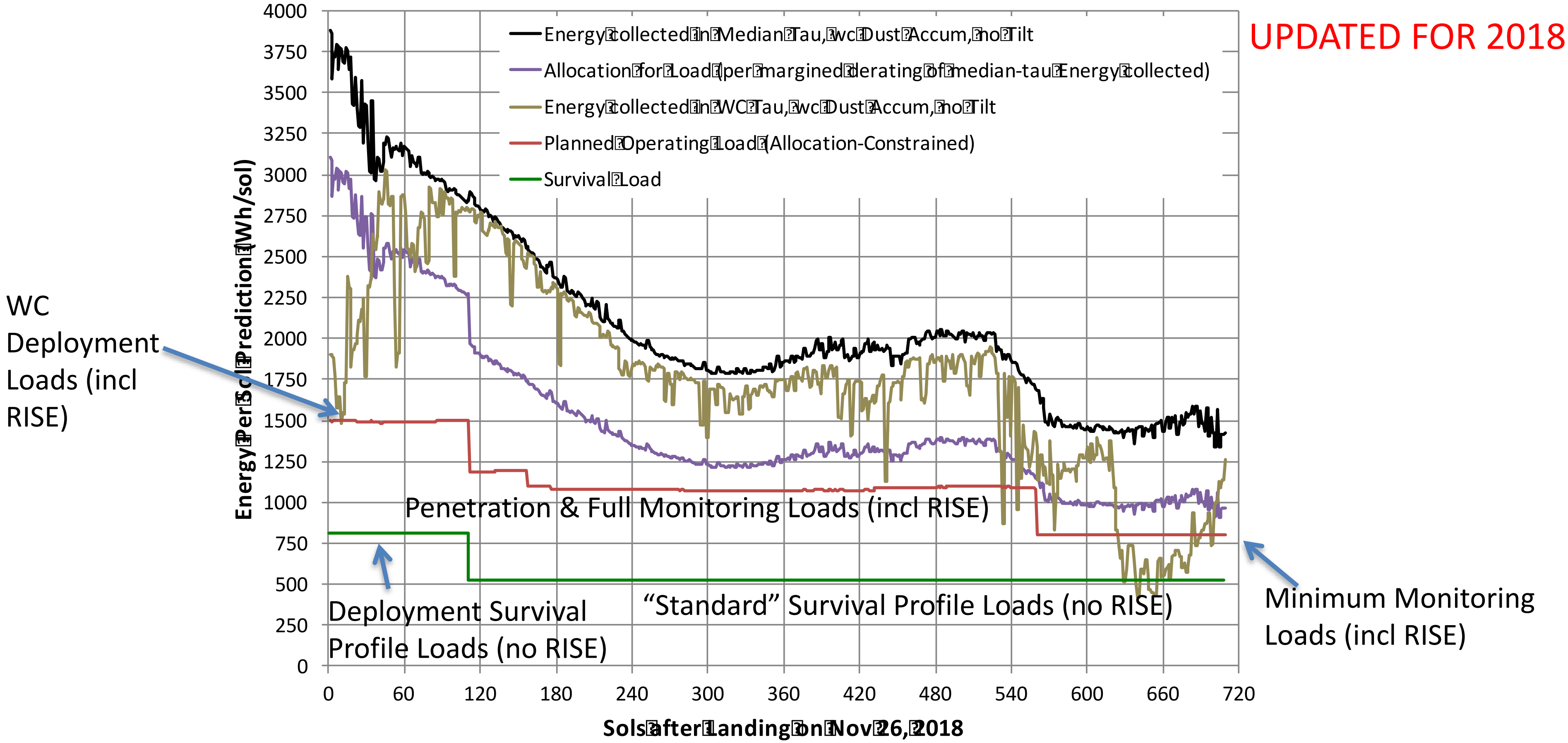
Stationary-rover solar energy generation variability curves



- The statistical curves above show – for all 726 sols (blue symbols, prior page) of the Spirit Rover's extended stationary periods on Mars and not during any regional or global dust storm - the average, 95% and 99% *maximum reduction* in collected energy, between:
  - a "zeroth" sol where energy is measured/estimated, and
  - another sol that is one of N sols contiguously after the zeroth sol.

Project Policy - These curves are the basis of InSight's derating of allocated energy, over and above the 15% energy margin policy vs model uncertainty, as a function of (1) sequence duration and (2) uncertainty / risk level.

Median-Energy vs WC Energy: Allocation for Sequencing, FP for Survival



- The black curve is the energy collected per sol at 5N latitude with no array tilt, median (expected-value) tau per sol, and ERD dust accumulation (no wind cleanings) – conservative "expected value" for flight.
- The blue curve is the energy allocated for load planning (with project policy margins for model error and Spirit-based variability). Red load curve planned in operations, subject to blue curve as upper constraint.
- The gold curve is the energy collected with no array tilt, worst-observed tau in the ERD per sol, and ERD dust accumulation. **When FP sees energy go below red curve, safe mode -> go to green load curve.**

Energy Management Use Case Scenarios

Surface Operations Scenario:	1. Post-landing Commisioning Period	2. Deployment Period	3. Penetration/Monitoring Period	4. Dust Storm
Nominal Sols	0 – ~4 (planned 1st tau obs)	~5 - 44	45 - 709	~3 for regional storm, ~45 for global storm
Sequence Support Interval	Daily/Tactical	Daily/Tactical (with strategic forecast ~ weekly)	Weekly (with strategic forecast ~ monthly)	Daily/Tactical (with forecasts after storm peaks)
Tau Observation Frequency	None or Few	Daily	Weekly	Goal: Daily / as available
Key Load Profiles to be evaluated	Spacecraft and payload check-out/commissioning activities	Max Deployment, Conserve, Minimum	Max Penetration, Full, Conserve, Minimum + Cold Season Heaters	Survival Profile
Margin Policy: energy margin held for load allocations	25% for model predict uncertainty + 5% for env. variability	15% for model predict uncertainty + 5% for env. variability	15% for model predict uncertainty + 17% [TBC] env. variability	15% + all remaining available (Survival is Minimum-Energy Profile)

Energy Rules/Criteria for Sequence Planning, *as of Jul 15, 2015*

If energy-trending data - and tau/environment observations as available - indicate presence of a dust storm, then ground is to command entry into a survival profile.

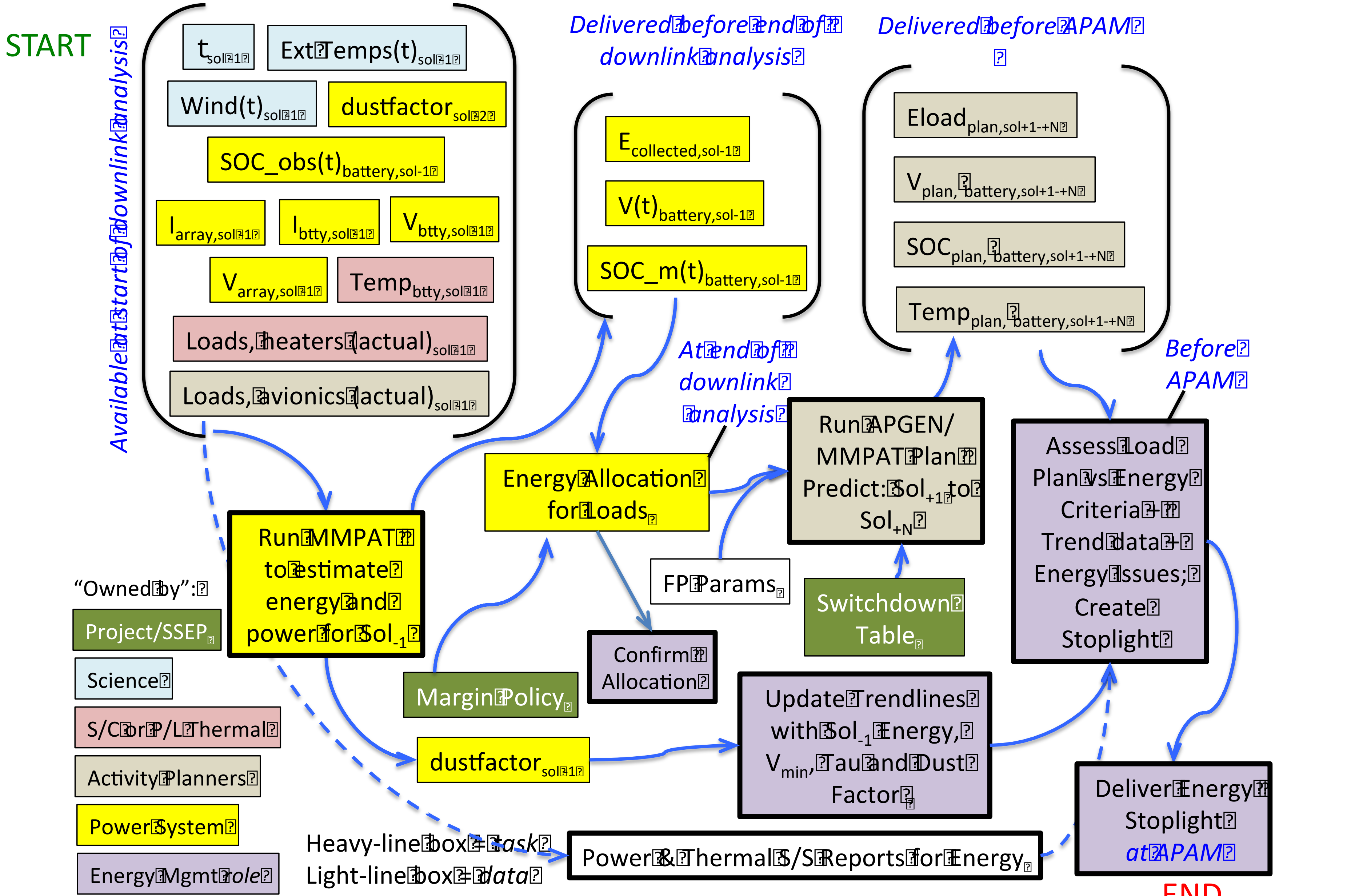
Otherwise, a planned deployment or science sequence is deemed “Go” for energy by the energy management lead if all of the following are satisfied in the energy model:

1) Energy Allocation Sufficiency: The margined and derated Energy Allocation for the upcoming sequence is above the FP modeled energy monitor threshold (unless we are planning to be in Survival and/or spacecraft safe mode)
2) Energy Load Compliance: Predicted per-sol loads for each sol of the sequence period (including all heaters) consume less energy than the per-sol Energy Allocation for that sequence
3) Battery State of Charge Sufficiency: Minimum battery state of charge predicted each sol, based on 99%-low collected energy occurring each sol, is above the FP SOC monitor threshold
4) Predicted battery temperature* does not exceed hot AFT's during the sequence interval

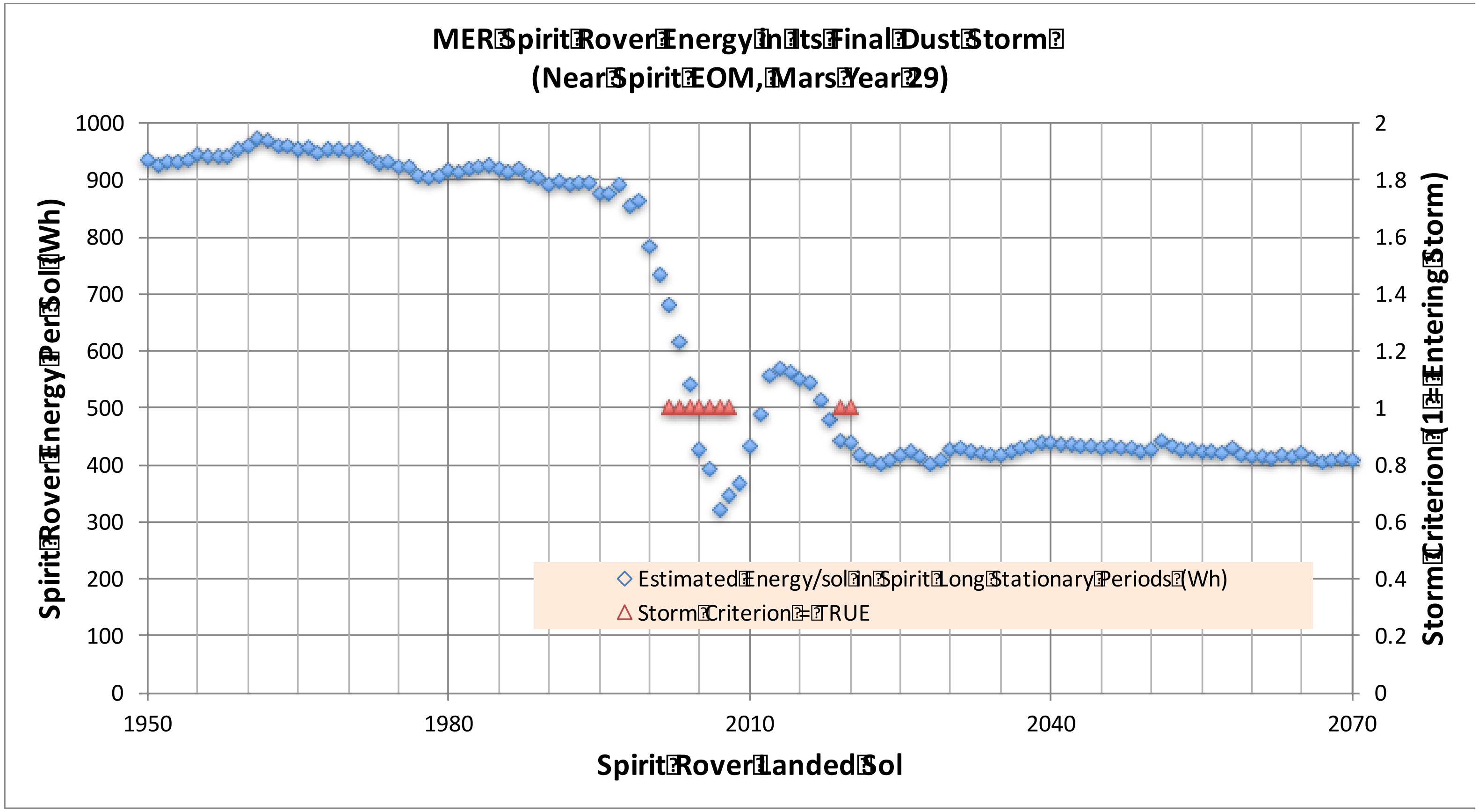
If any of (1) – (4) is not true, energy management lead will report on the specific risks of sending up the sequence with the violation(s) unremedied, and suggest one or more load reductions to remedy the violation(s).

* *(Other non-battery equipment approaching hot AFT may also trigger load shedding.)*

Data Flow Concept for Energy Confirmation Process



So, What if there *IS* a Dust Storm?



- Discuss “can we detect a dust storm rising?”

- point to weekly weather reports from orbit, but in absence of tau or orbiter weather reports, MER historic data indicate that trending of energy data can give a reasonable determination.

Wrapping Up

- Even with later arrival after the early dust storm, surface energy management remains a key area for InSight, due to:
  - Long-term operations and successful science return for Mars seismometry and RISE core radius estimation
    - Needs to be conservative with battery but not so conservative as to reduce important, daily accumulation of science results.
  - Late dust storm season now poses more challenges for near-end-of-mission end game